Evaluating the Effectiveness of Gamification on Physical Activity: Systematic Review and Meta-analysis of Randomized Controlled Trials

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Multimedia Appendix 1:

Supplementary Materials

- 1. Supplemental figures referred in the manuscript
- 2. Search equations for databases

All Data and materials are available on the OSF page of the project (https://osf.io/x2483/)

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1. Supplemental figures referred in the manuscript

Table S1 Keywords used for database searches

Physical activity and sedentary behaviors	Gamification	e-he	Trial	
exercise sport "active living" "active transport" "exercise therapy" fitness sedent* "sitting time" inactive inactivity walk*	gamification exergaming game gamified gaming gameful* multiplayer player playing	telemedicine telehealth e-health m-health mobile internet applications smartphone cellphone Iphone facebook	iOS android website digital* electronic* device framework* wearable "social network" Technolog*	"randomized controlled trial" RCT randomized trial "clinical trial" "controlled trial"

N.B. Some additional terms and synonyms could be used for some database. For more information, see search strings for each database.

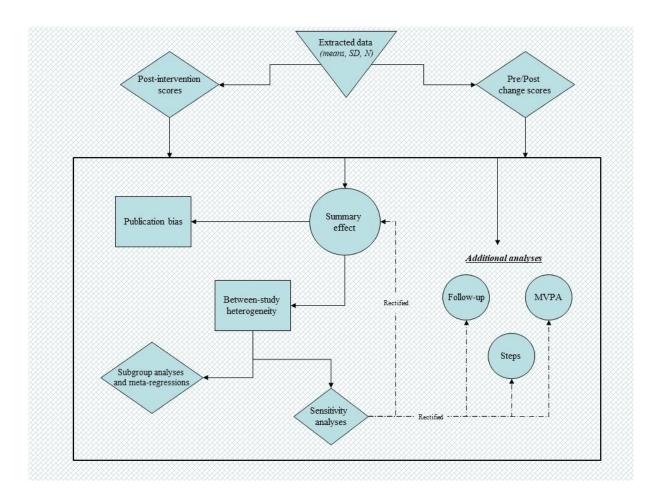


Fig. S1 Statistical analyses summary. All analyses were conducted two times, both for post-intervention scores and for pre/post intervention change scores

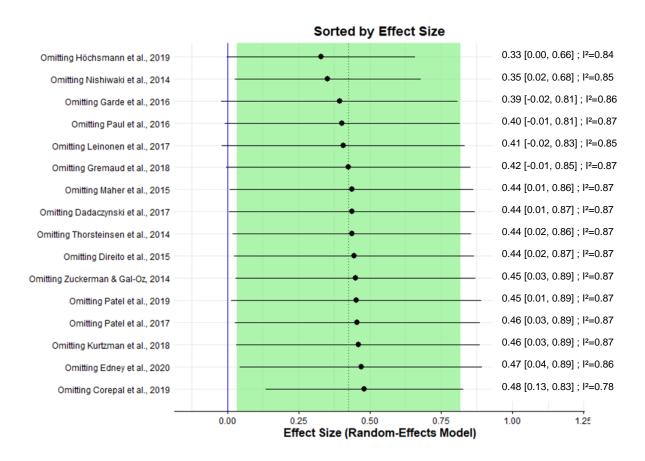


Fig. S2 Forest plots representing Leave-one-out analyses ordered by effect size (Hedge's *g*; low to high)

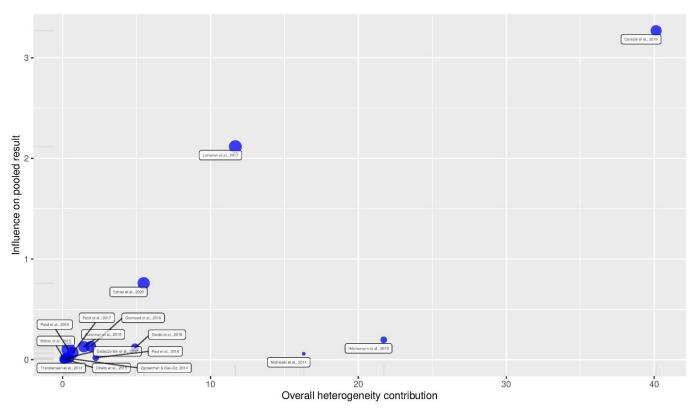


Fig. S3 Baujat plot representing the contribution of each study to the overall heterogeneity (measured by Cochran's Q) in function of its influence on the pooled effect size

Study or Subgroup	Expe Mean	erimental SD	Total	Mean	Control SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	
Population = Adults	F20 F	240.50	00	442.0	200.20	0.4	0.00/	0.0710.04.0.701	<u>.</u>
Dadaczynski et al., 2017	526.5					64	8.6%	0.37 [0.04; 0.70]	_
Edney et al., 2020	108.7			108.9		130	9.7%	-0.00 [-0.25; 0.24]	₹ <u></u>
Gremaud et al., 2018		2775.00			2775.00		8.6%	0.52 [0.19; 0.85]	**
Höchsmann et al., 2019		1334.00			1280.00		3.3%	2.41 [1.52; 3.31]	<u> </u>
Kurtzman et al., 2018		2198.20			1949.00		9.1%	0.11 [-0.19; 0.40]	₹
Maher et al., 2015	528.0				371.00		7.7%	0.36 [-0.04; 0.76]	
Patel et al., 2017		3382.00			3836.00	100	9.2%	0.17 [-0.12; 0.45]	<u>₹</u>
Patel et al., 2019		2530.56			2142.00		10.4%	0.35 [0.16; 0.53]	
Paul et al., 2016	5791.0	2952.00	15	2947.0	2399.00	8	3.2%	0.99 [0.07; 1.90]	
Thorsteinsen et al., 2014	574.4	434.74	12	501.9	232.90	8	3.3%	0.19 [-0.71; 1.08]	- •
Zuckerman & Gal-Oz, 2014	45.5	22.11	41	43.6	20.36	18	5.9%	0.09 [-0.47; 0.64]	- <mark> - - - -</mark>
Total (95% CI)			1075			684	79.1%	0.36 [0.03; 0.69]	★
Heterogeneity: Tau ² = 0.0761	; Chi ² = 3	34.8, df = 1	0 (P <	0.01); I2	= 71%				
Population = Adolescent	s								
Direito et al., 2015	33.0	20.61	17	30.5	17.99	18	4.9%	0.13 [-0.54; 0.79]	- - - - - - - - - -
Garde et al., 2016	14.8	4.82	28	11.2	2.87	28	5.9%	0.91 [0.36; 1.46]	
Leinonen et al., 2017	71.5	30.80	187	52.8	24.40	160	10.1%	0.67 [0.45; 0.88]	
Total (95% CI)			232			206	20.9%	0.63 [-0.16; 1.41]	
Heterogeneity: Tau ² = 0.0354	: Chi ² = 3	3.27. df = 2	P = 0).19): I ² =	39%			. , .	
Total (95% CI)			1307			890	100.0%	0.42 [0.14; 0.69]	 ♦
Heterogeneity: Tau ² = 0.0846	: Chi ² = 4	49.21. df =	13 (P ·	< 0.01); l ²	2 = 74%			- / -	
Residual heterogeneity: Tau ²						3%			-3 -2 -1 0 1 2 3
	,		,	•	,,				

Fig. S4 Forest plot with age subgroups (adults versus adolescents) for the effect of gamification versus control on post-intervention PA outcomes (moderate-to-vigorous physical activity

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(MVPA), daily step count, number of active minutes, and walking time). SD standard deviation, Std standardized, IV inverse variance, CI confidence interval, Tau², Chi², and I² measures of between-study heterogeneity

Study or Subgroup	Experime Mean	ntal SD Total	Mean	Control SD		Weight	Std. Mean Difference IV, Random, 95% C	
Pathology = No	EDG E 040	0.56 80	442.9	200.26	64	0.60/	0.37 [0.04; 0.70]	<u> </u>
Dadaczynski et al., 2017 Direito et al., 2015).56 80).61 17			64 18	8.6% 4.9%	0.13 [-0.54; 0.79]	
Edney et al., 2020		3.30 129				9.7%	-0.00 [-0.25; 0.24]	<u></u>
Garde et al., 2016		1.82 28			28	5.9%	0.91 [0.36; 1.46]	T
Gremaud et al., 2018	8460.0 2775			2775.00	72	8.6%	0.52 [0.19; 0.85]	
Leinonen et al., 2017		0.80 187			160	10.1%	0.67 [0.45; 0.88]	
Maher et al., 2015		.00 47			51	7.7%	0.36 [-0.04; 0.76]	 •
Patel et al., 2017	8905.0 3382	2.00 94	8298.0	3836.00	100	9.2%	0.17 [-0.12; 0.45]	
Thorsteinsen et al., 2014	574.4 434	.74 12	501.9	232.90	8	3.3%	0.19 [-0.71; 1.08]	- •
Zuckerman & Gal-Oz, 2014	45.5 22	2.11 41	43.6	20.36	18	5.9%	0.09 [-0.47; 0.64]	- <mark> =</mark>
Total (95% CI)		707			649	74.0%	0.35 [0.15; 0.55]	🕈
Heterogeneity: Tau ² = 0.055	4; Chi ² = 24.3, c	f = 9 (P < 0).01); l ² =	63%				
Pathology = Yes	07000 400		0550.0			0.00/	0.447450.0043	_
Höchsmann et al., 2019	9783.0 1334			1280.00		3.3%	. , .	<u>_</u>
Kurtzman et al., 2018	5935.4 2198			1949.00	66	9.1%	0.11 [-0.19; 0.40]	T.
Patel et al., 2019	7008.6 2530			2142.00		10.4%	0.35 [0.16; 0.53]	
Paul et al., 2016	5791.0 2952	600 600		2399.00	8	3.2%		
Total (95% CI) Heterogeneity: Tau ² = 0.284	4; Chi ² = 24.91,			= 88%	241	26.0%	0.79 [-0.77; 2.34]	
,		,	,,					
Total (95% CI)		1307		,	890	100.0%	0.42 [0.14; 0.69]	<u> </u>
Heterogeneity: Tau ² = 0.084					201			
Residual heterogeneity: Tau	$= NA; Chi^- = 4$	9.21, df = 1	2(P < 0.	υ1); r = /6	5%			-3 -2 -1 0 1 2 3

Fig. S5 Forest plot with health condition subgroups (healthy people versus patients with chronic diseases) for the effect of gamification versus control on post-intervention PA outcomes (moderate-to-vigorous physical activity (MVPA), daily step count, number of active minutes, and walking time). *SD* standard deviation, *Std* standardized, *IV* inverse variance, *CI* confidence interval, *Tau*², *Chi*², and *P* measures of between-study heterogeneity

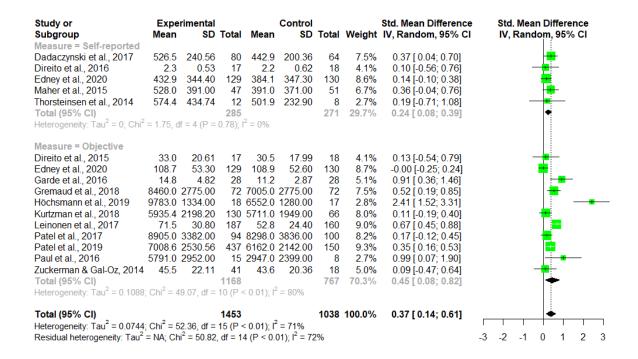


Fig. S6 Forest plot with type of measure subgroups (self-reported versus objective measures) for the effect of gamification versus control on post-intervention PA outcomes (moderate-to-vigorous physical activity (MVPA), daily step count, number of active minutes, and walking time). *SD* standard deviation, *Std* standardized, *IV* inverse variance, *CI* confidence interval, Tau^2 , Chi^2 , and I^2 measures of between-study heterogeneity

Study or Subgroup	Experimenta Mean SE	l Total Mea	Control n SD		Weight	Std. Mean Difference IV, Random, 95% CI			
intervention.duration.red	tif = FALSE				_				
Dadaczynski et al., 2017	526.5 240.56	80 442.	9 200.36	64	8.6%	0.37 [0.04; 0.70]	 		
Direito et al., 2015	33.0 20.61	I 17 30.	5 17.99	18	4.9%	0.13 [-0.54; 0.79]	- <mark> =</mark> -		
Garde et al., 2016	14.8 4.82	2 28 11.	2 2.87	28	5.9%	0.91 [0.36; 1.46]	 		
Gremaud et al., 2018	8460.0 2775.00	72 7005.	0 2775.00	72	8.6%	0.52 [0.19; 0.85]	 		
Maher et al., 2015	528.0 391.00	47 391.	0 371.00	51	7.7%	0.36 [-0.04; 0.76]	 <u> </u>		
Paul et al., 2016	5791.0 2952.00	15 2947.	0 2399.00	8	3.2%	0.99 [0.07; 1.90]			
Zuckerman & Gal-Oz, 2014	45.5 22.11	I 41 43.	6 20.36	18	5.9%	0.09 [-0.47; 0.64]	- <mark> - </mark> - - - - - - - - -		
Total (95% CI)		300		259	44.9%	0.44 [0.19; 0.69]	♦		
Heterogeneity: Tau ² = 0.010	9; Chi ² = 7.16, df =	$6 (P = 0.31); I^2$	= 16%						
intervention.duration.red									
Edney et al., 2020	108.7 53.30				9.7%	-0.00 [-0.25; 0.24]	<mark>∓</mark>		
Höchsmann et al., 2019	9783.0 1334.00) 18 6552.	0 1280.00	17	3.3%	2.41 [1.52; 3.31]	<u> </u>		
Kurtzman et al., 2018	5935.4 2198.20			66	9.1%	0.11 [-0.19; 0.40]	<mark>≠</mark>		
Leinonen et al., 2017	71.5 30.80				10.1%	0.67 [0.45; 0.88]			
Patel et al., 2017	8905.0 3382.00	94 8298.	0 3836.00	100	9.2%		<u>=</u>		
Patel et al., 2019	7008.6 2530.56				10.4%	0.35 [0.16; 0.53]			
Thorsteinsen et al., 2014	574.4 434.74	12 501.	9 232.90	8	3.3%	0.19 [-0.71; 1.08]	- -		
Total (95% CI)		1007		631	55.1%	0.41 [-0.19; 1.01]	 • • • • • • • • • • • • • • • • • • •		
Heterogeneity: $Tau^2 = 0.1236$; $Chi^2 = 40.88$, $df = 6$ (P < 0.01); $I^2 = 85\%$									
Total (95% CI)	2	1307	2	890	100.0%	0.42 [0.14; 0.69]	•		
Heterogeneity: Tau ² = 0.084									
Residual heterogeneity: Tau	-3 -2 -1 0 1 2 3								

Fig. S7 Forest plot with subgroups in function of intervention duration (less than 12 weeks versus 12 weeks or more) for the effect of gamification versus control on post-intervention PA outcomes (moderate-to-vigorous physical activity (MVPA), daily step count, number of active

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minutes, and walking time). SD standard deviation, Std standardized, IV inverse variance, CI confidence interval, Tau², Chi², and I² measures of between-study heterogeneity

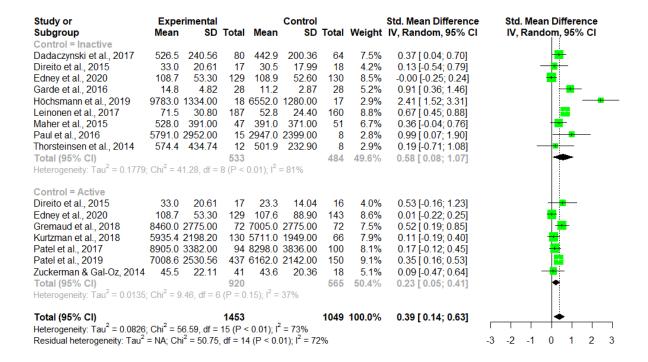


Fig. S8 Forest plot with control groups subgroups (inactive control group versus active control group) for the effect of gamification versus control on post-intervention PA outcomes (moderate-to-vigorous physical activity (MVPA), daily step count, number of active minutes, and walking time). *SD* standard deviation, *Std* standardized, *IV* inverse variance, *CI* confidence interval, *Tau*², *Chi*², and *I*² measures of between-study heterogeneity

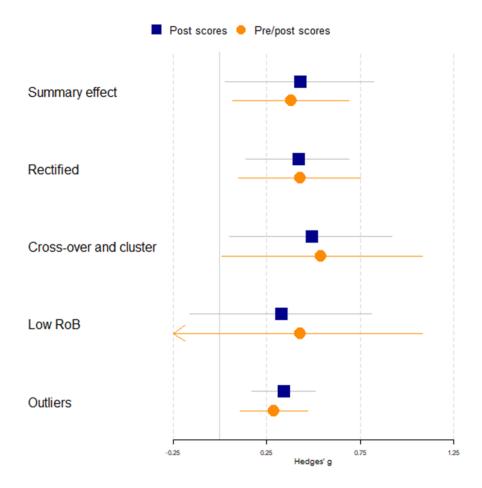


Fig. S9 Summary of the meta-analyses conducted on global PA (i.e., summary effect of gamification versus control, rectified effect after 'sensitivity analysis', effect after removing cross-over and cluster trials, effect after removing studies with a high Risk of Bias (RoB), and effect after removing outliers) both for post-intervention scores and pre/post intervention change scores

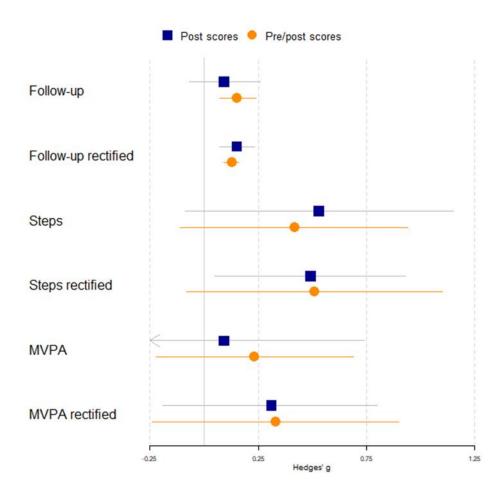


Fig. S10 Summary of the meta-analyses conducted on other outcomes (i.e., effect of gamification versus control after a follow-up period (from 12 to 24 weeks after the end of the intervention), effect on steps outcomes, effect on moderate-to-vigorous physical activity (MVPA), and rectified effects after 'sensitivity analyses') both for post-intervention scores and pre/post intervention change scores

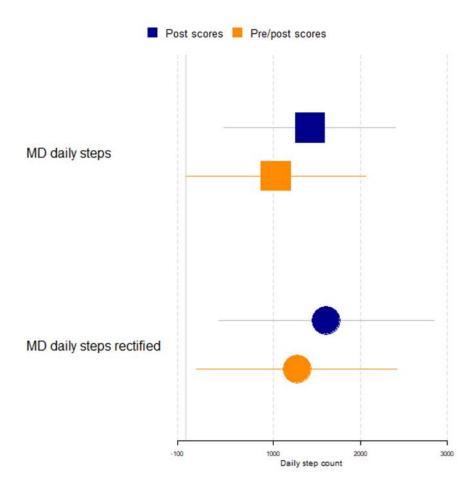


Fig. S11 Summary of the meta-analyses conducted on daily steps (i.e., mean difference of daily steps between gamification and control) both for post-intervention scores and pre/post intervention change scores

2. Search equations for databases

Search String PubMed (615)

- #1. ("exercise"[MH] OR "exercise"[TW] OR "exercises"[TW] OR "active living"[TW] OR "active transport"[TW] OR "activities, physical"[TW] OR "activity, physical"[TW] OR "physical activities"[TW] OR "physical activity"[TW] OR "exercise therapy"[MH] OR "physical fitness"[MH] OR fitness[TW] OR sedent*[TW] OR "sitting time"[TW] OR inactive[TW] OR walk*[TW])
- #2. (gamification[TW] OR exergaming[TW] OR "exer-gaming"[TW])
- #3. (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR clinical trials as topic[mesh:noexp] OR randomly[tiab] OR trial[ti])
- #4. #1 AND #2 AND #3
- #5. (game[TW] OR games[TW] OR gamified[TW] OR gaming[TW] OR gameful*[TW] OR multiplayer[TW] OR player[TW] OR players[TW] OR playing[TW])
- #6. ("telemedicine"[MH] OR "telemedicine"[TW] OR "telehealth"[TW] OR e-health[TW] OR m-Health[TW] OR eHealth[TW] OR mHealth[TW] OR "mobile applications"[MH] OR "applications"[TW] OR "application"[TW] OR apps[TW] OR "online"[TW] OR "mobile"[TW] OR "internet"[TW] OR "web based"[TW] OR "Smartphone"[MH] OR "phone, smart"[TW] OR "smart phones"[TW] OR "smartphones"[TW] OR "smart phone"[TW] OR "phones, smart"[TW] OR "Smartphone"[TW] OR "cell phone"[TW] OR Iphone[TW] OR android[TW] OR iOS[TW] OR "Wearable Electronic Devices"[MH] OR website[TW] OR digital*[TW] OR system*[TW] OR electronic*[TW] OR technolog*[TW] OR device[TW] OR framework*[TW] OR "social support"[Mesh:NoExp] OR "facebook"[TW] OR "networks, social"[TW])
- #7. #1 AND #3 AND #5 AND #6
- #8. #4 OR #7

Filters: English, from 2010-2020

Search String EMBASE (491)

('sport'/exp OR 'exercise'/exp OR 'physical activity' OR 'climbing'/exp OR 'walking'/exp OR 'sitting'/exp) AND ('exergame'/exp OR 'exergaming'/exp OR 'active video game'/exp OR exergam*:ti,ab,kw OR 'active video gam*':ti,ab,kw OR 'active videogam*':ti,ab,kw OR 'active videogam*':ti,ab,kw OR 'gamification'/exp OR 'gamifi*':ti,ab,kw OR (('recreational game'/exp OR 'game-based':ti,ab,kw OR 'gam*':ti,ab,kw) AND ('telehealth'/exp OR 'mobile application'/exp OR 'smartphone'/exp OR 'wearable computer'/exp OR 'social network'/exp OR 'virtual reality'/exp))) AND ('clinical trial'/de OR 'controlled clinical trial'/de OR 'randomized controlled trial'/de OR 'randomized controlled trial'/de OR 'randomized controlled trial topic'/de) AND [embase]/lim NOT ([embase]/lim AND [medline]/lim)

- #1. ("exercise":ti,ab,kw OR "exercises":ti,ab,kw OR "active living":ti,ab,kw OR "active transport":ti,ab,kw OR "activities, physical":ti,ab,kw OR "activity, physical":ti,ab,kw OR "physical activities":ti,ab,kw OR "physical activity":ti,ab,kw OR fitness:ti,ab,kw OR sedent*:ti,ab,kw OR "sitting time":ti,ab,kw OR inactive:ti,ab,kw OR inactivity:ti,ab,kw OR walk*:ti,ab,kw)
- #2. (gamification:ti,ab,kw OR exergaming:ti,ab,kw OR "exer-gaming":ti,ab,kw)
- #3. #1 AND #2
- #4. (game:ti,ab,kw OR games:ti,ab,kw OR gamified:ti,ab,kw OR gaming:ti,ab,kw OR gameful*:ti,ab,kw OR multiplayer:ti,ab,kw OR player:ti,ab,kw OR players:ti,ab,kw OR playing:ti,ab,kw)
- #5. ("telemedicine":ti,ab,kw OR "telehealth":ti,ab,kw OR "e-health":ti,ab,kw OR "mHealth":ti,ab,kw OR "applications":ti,ab,kw OR "applications":ti,ab,kw OR "applications":ti,ab,kw OR "applications":ti,ab,kw OR "applications":ti,ab,kw OR "mobile":ti,ab,kw OR app:ti,ab,kw OR app:ti,ab,kw OR "online":ti,ab,kw OR "mobile":ti,ab,kw OR "internet":ti,ab,kw OR "web based":ti,ab,kw OR "phone, smart":ti,ab,kw OR "smart phones":ti,ab,kw OR "smart phone":ti,ab,kw OR "phones, smart":ti,ab,kw OR "Smartphone":ti,ab,kw OR "cell phone":ti,ab,kw OR Iphone:ti,ab,kw OR android:ti,ab,kw OR iOS:ti,ab,kw OR website:ti,ab,kw OR device:ti,ab,kw OR system*:ti,ab,kw OR electronic*:ti,ab,kw OR technolog*:ti,ab,kw OR device:ti,ab,kw OR "social network*:ti,ab,kw OR "network, social":ti,ab,kw OR "social support":ti,ab,kw OR "social network":ti,ab,kw OR "social networking":ti,ab,kw OR virtual*:ti,ab,kw)
- #6. #1 AND #4 AND #5
- #7. #3 OR #6

Limit: Publication Year from 2010 to 2020 in Trials.

Search String Scopus (306)

((TITLE ("physical activity" OR sport OR exercise? OR walking OR fitness OR "active living" OR "active transport" OR sedent* OR "sitting time" OR inactiv* OR (physical AND near/1 AND activit*))) AND (TITLE-ABS-KEY ("randomi?ed controlled trial" OR "randomi?ed clinical trial" OR "controlled clinical trial" OR randomi?ed OR rct)) AND (TITLE-ABS-KEY (gamifi* OR exergam* OR "exer-gam*"))) OR ((TITLE ("physical activity" OR sport OR exercise? OR walking OR fitness OR "active living" OR "active transport" OR sedent* OR "sitting time" OR inactiv* OR (physical AND near/1 AND activit*))) AND (TITLE-ABS-KEY ("randomi?ed controlled trial" OR "randomi?ed clinical trial" OR "controlled clinical trial" OR randomi?ed OR rct)) AND (TITLE-ABS-KEY (game? OR multiplayer OR player? OR playing OR play)) AND (TITLE-ABS-KEY (telemedicine OR telehealth OR "e-health" OR "m-Health" OR ehealth OR "mHealth" OR application? OR app? OR online OR mobile OR internet OR "web based" OR "phone, smart" OR "smart phones" OR "smart phones" OR "smart phone" OR "phones, smart" OR "Smartphone" OR "cell phone" OR iphone OR android OR "iOS" OR website OR digital* OR system* OR electronic* OR technolog* OR device OR framework* OR "facebook" OR "networks, social" OR "social network" OR "network, social" OR "social support" OR "support, social" OR "social networking" OR virtual*))) AND (LIMIT-TO

(PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012) OR LIMIT-TO (PUBYEAR, 2011) OR LIMIT-TO (PUBYEAR, 2010)) AND (LIMIT-TO (LANGUAGE, "English"))

Search String Web of Science (89)

- #1. TI = ("physical activity" OR sport OR exercise? OR walking OR fitness OR "active living" OR "active transport" OR sedent* OR "sitting time" OR inactive OR inactivity OR (physical NEAR/1 activit*))
- #2. TI = (gamifi* OR exergam* OR exer-gam*)
- #3. TS= ("clinical trial*" OR "controlled trial*" OR "follow-up stud*" OR "prospective stud*" OR "random*" OR "single blind*" OR "double blind*" OR rct)
- #4. #1 AND #2 AND #3
- #5. TS= (telemedicine OR telehealth OR e-health OR m-Health OR eHealth OR mHealth OR application? OR app? OR online OR mobile OR internet OR "web based" OR "phone, smart" OR "smart phones" OR "smart phones" OR "smart phone" OR "phones, smart" OR "Smartphone" OR "cell phone" OR Iphone OR android OR "iOS" OR website OR digital* OR system* OR electronic* OR technolog* OR device OR framework* OR facebook OR "networks, social" OR "social network" OR "network, social" OR "social support" OR "support, social" OR "social networking" OR virtual*)
- #6. TI = (game? OR multiplayer OR player? OR playing OR play)
- #7. #1 AND #3 AND #5 AND #6
- #8. #4 OR #7